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EXPERIMENTAL EVIDENCE FOR A LOW ION TRANSITION ALTITUDE IN THE UPPER NIGHTTIME IONOSPHERE

BY

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A Scout rocket fired from Wallops Island, Virginia on March 29, 1962 at 2:27 AM local time, was instrumented for measuring ionosphere electron and ion densities by means of a two-frequency cw propagation beacon and a positive ion trap retarding potential experiment, respectively. Although vehicle performance was good (6000 km apogee) instrumentation difficulties encountered during fourth stage burning severely limited the scientific mission of the payload. However, electron density values were obtained at altitudes up to 750 km and an ion density profile up to 2800 km. The latter result is the principle subject of this paper.

The positive ion retarding potential experiment was similar to that flown successfully on the Explorer VIII satellite (Bourdeau, Donley and Whipple, 1962; Bourdeau, Whipple, Donley and Bauer, 1962), on a Scout rocket (Hale, 1961), and on a Javelin rocket (Hanson and McKibbin, 1961).

The planar ion trap consisted of aperture, retarding potential and electron suppressor grids, constructed of a wire mesh, and a current collector plate. The ion current was measured with a 100% feedback linear response electrometer amplifier.

Measurements of positive ion concentration are obtained from the collector currents when the voltage on the retarding grid is negative relative to the ambient plasma such that there is no retardation of incoming ions. Under these conditions, the collector current I_+ is related to the ion concentration N_+ by (Whipple, 1959)

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$$I_+ = \alpha_+ A e N_+ V \cos\theta \left[1/2 + 1/2 \operatorname{erf}(V/a) + \frac{a \exp(-V^2/a^2)}{2\sqrt{\pi} V \cos\theta} \right] \quad (1)$$

where α_+ is the combined electrical transparency of the grids for ions, A is the collector area, e is the electronic charge, V is the vehicle velocity, θ is the angle between the vehicle velocity and trap normal, and a is the most probable thermal ion velocity. During the lower portion of the flight for which data is presented, θ is sufficiently small and the vehicle velocity is sufficiently greater than the ion thermal velocity so that the collector current can be represented with small error by

$$I_+ = \alpha_+ A e N_+ V. \quad (2)$$

The positive ion density profile obtained is shown in Figure 1. A value of 0.90 was used for the ion transparency in the data reduction. This value is consistent with an in-flight calibration of such grids on the Explorer VIII satellite (Bourdeau, Donley, Serbu and Whipple, 1961). The ion trap data are in good agreement with values of electron density obtained from the ground-ionosonde at Wallops Island at the F_2 max altitude and from Faraday rotation data at 73.6 Mc/s from the cw propagation experiment up to 750 km.

There are two portions of the profile above the F_2 maximum where the electron-ion scale height is nearly constant. These occur in the region 350-500 km' (geopotential altitude) and above 1000 km'. Assuming that the predominant ions in these two regions are O^+ and H^+ respectively, the scale heights in both regions are consistent with a neutral gas temperature of $800 \pm 150^\circ K$.

The presence of helium ions is not obvious from this nighttime profile since there is no altitude region corresponding to a He^+ scale height as evident in daytime profiles (Hanson, 1962; Bauer and Jackson, 1962). This is direct evidence that there is a large diurnal variation in the thickness of the upper ionosphere helium ion layer contrary to the conclusion of Hanson (1962). Bauer (1962) has pointed out that there should be a diurnal variation in the thickness of the helium ion layer. The profile presented in Figure 1 is in good agreement with a nighttime electron density profile obtained by Ulwick and Pfister (1962).

A more recent topside ionosphere model (Bauer, 1963) takes into account the diurnal variation of hydrogen content at a constant reference level. This indicates large diurnal variations in the helium ion layer thickness and also shows that for atmospheric temperatures less than 1000^{o}K the helium ion layer thickness is less than the scale height for helium ions and no distinguishable slope corresponding to He^+ is evident in electron or ion density profiles. Consequently, the determination of ion composition from a charged particle density profile requires a careful analysis of the shape of the profile in the ion transition altitude region. On the assumption of an isothermal, multiple-constituent ionosphere in diffusive equilibrium, the fit of the experimental data with a theoretical model (Bauer, 1962) in the region of transition between the constant scale height regions requires a ternary mixture of O^+, He^+ and H^+. The best fit, shown in Figure 1 with a solid line, assumed a temperature of 800^{o}K and a ratio of He^+ to O^+ of 4.0×10^{-2} and H^+ to O^+ of 7.0×10^{-3} at a reference altitude of 350 km' (geopotential altitude). The transitions from O^+ to He^+ as the predominant constituent are at 580 km (530 km') and from He^+ to H^+ at 840 km (740 km') suggesting a helium ion layer about 260 km thick. This is in good agreement with the prediction by Bauer (1963) of a helium ion layer with a thickness of about 300 km for an atmospheric temperature of 800^{o}K, although the transition altitudes for the profile are about 200 km lower than in Bauer's model.

A partial failure in the ion trap occurred at an altitude of about 475 km during a period of combustion resonance burning of the fourth stage motor. This failure apparently did not adversely affect the ion density determination because ion densities computed after the failure are in good agreement with electron densities obtained from Faraday rotation data. Also the scale heights above and below are in approximate agreement.

The partial failure resulted in unreasonably high ion temperatures being obtained from the maximum slope of the retarding potential curves. Prior to failure values of about $1600^{\circ}K$ are obtained from the data assuming O^{+} to be the dominant constituent, and above 475 km the apparent temperature abruptly jumps to values in excess of $10{,}000^{\circ}K$. Although the value of $1600^{\circ}K$ is high in comparison with the $800^{\circ}K$ value obtained from the ion scale height of the profile, the value is consistent with temperatures obtained by Hanson and McKibbin (1961) using a similar ion trap. This factor of two most likely is due to an enhancement in the normal component of the particle energy caused by a non-planar sheath geometry (Hinteregger, private communication). This factor is not considered in Whipple's (1959) theoretical relationship used for analysis. Under normal operation, this factor of two would not impair the trap's ion resolution enough to prevent correct identification of ionic constituents from the volt-ampere curves.

The symptoms of the partial failure are such that the effective amplitude of the retarding potential appears attenuated. This could arise from ruptures in the retarding grid structure. This would allow measurement of total ion current but the volt-ampere characteristics of the retarding potential curves could not be used for determining ionic composition through the use of Whipple's (1959) theoretical relationship.

It has been shown from the experimental ion density profile, which is valid despite the indicated partial failure, that the transition altitude from heavy to light ions occurs at about 600 km in a nighttime ionosphere, and that the thickness of the helium ion layer in the upper ionosphere shows large variations as a function of the neutral gas temperature.

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FIGURE CAPTION

Figure 1. An ion density profile obtained with an ion trap experiment on a Scout rocket at Wallops Island, Virginia. The right-hand ordinate is geometric altitude and the left-hand ordinate is geopotential altitude which takes into account the altitude dependence of the acceleration of gravity. Ion trap data is shown by circles with error flags indicated. A theoretical model ionosphere is shown by a solid line. Faraday rotation data and the value of electron density of F_2 max altitude obtained from a ground ionosonde are indicated.

REFERENCES

Bauer, S. J., "On the structure of the topside ionosphere", J. Atmospheric Sciences, 19, 276-278, May 1962.

Bauer, S. J., "Helium ion belt in the upper atmosphere", Nature, 195, January 5, 1963.

Bauer, S. J. and Jackson, J. E., "Rocket measurement of the electron-density distribution in the topside ionosphere", J. Geophysical Research, 67, 1675-1677, 1962.

Bourdeau, R. E., Donley, J. L., Serbu, G. P., and Whipple, E. C. Jr., "Measurement of sheath currents and equilibrium potential on the Explorer VIII satellite", J. Astronautical Sciences, 8, 1961.

Bourdeau, R. E., Donley, J. L., and Whipple, E. C. Jr., "Instrumentation of the ionosphere direct measurements satellite (Explorer VIII)", NASA Technical Note, D-414, 1962.

Bourdeau, R. E., Whipple, E. C. Jr., Donley, J. L. and Bauer, S. J., "Experimental evidence for the presence of helium ions based on Explorer VIII satellite data", J. Geophysical Research, 67, 467-475, 1962.

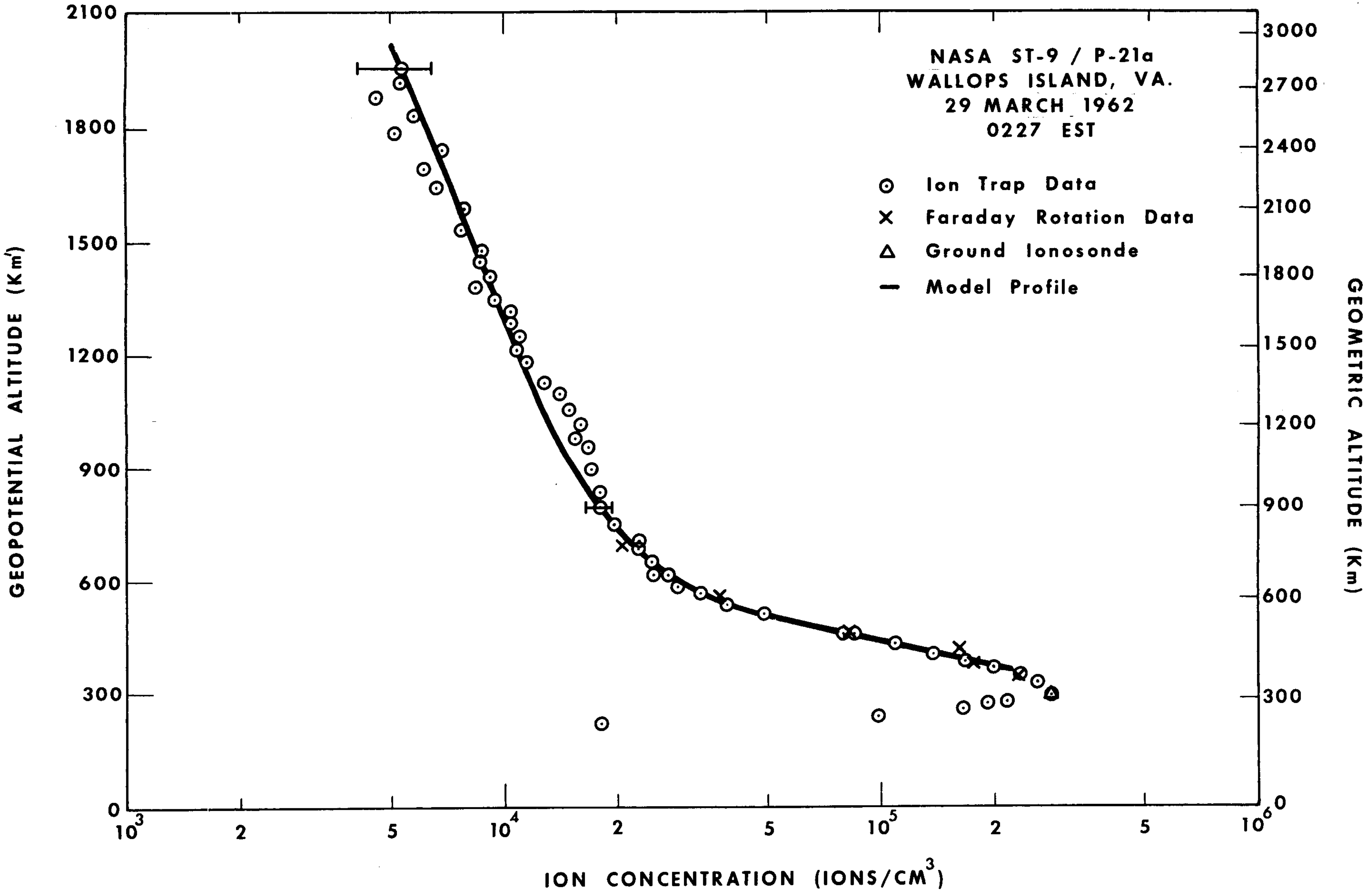
Hale, L. C., "Ionospheric measurements with a multigrid retarding potential analyzer", Abstract, J. Geophysical Research, 66, 1554, 1961.

Hanson, W. B., "Upper-atmosphere helium ions", J. Geophysical Research, 67, 183-188, 1962.

Hanson, W. B. and McKibbin, D. D., "An ion-trap measurement of the ion concentration profile above the F_2 peak", J. Geophysical Research, 66, 1667-1671, 1961.

Ulwick, J. C. and Pfister, W., "Spatial and temporal variations of electron density from an orbiting satellite", Presented at COSPAR meeting, Washington, D.C., May 1962.

Whipple, E. C. Jr., "The ion-trap results in exploration of the upper atmosphere with the help of the third Soviet sputnik", Proc. IRE, 47, 2023-2024, November 1959.



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WALLOPS ISLAND, VA.
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Ion Trap Data
Faraday Rotation Data
Ground Ionosonde
Model Profile
GEOPOTENTIAL ALTITUDE (Km')
GEOMETRIC ALTITUDE (Km)
ION CONCENTRATION (IONS/CM³)